

EJECTOR WITH THROTTLE CONTROLLABLE NOZZLE

AND EJECTOR CYCLE USING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

5 This application is related to and claims priority from
Japanese Patent Application No. 2002-199993 filed on July 9, 2002,
the contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

10 1. Field of the Invention:

The present invention relates to an ejector with a throttle controllable nozzle in which two opening degrees of a throat portion and an outlet of the nozzle can be controlled, and an ejector cycle using the ejector. The ejector has a fluid pumping function for circulating a fluid by entrainment of a drive fluid injected at a high speed.

15 2. Description of Related Art:

In an ejector cycle, pressure of refrigerant to be sucked into a compressor is increased by converting expansion energy to pressure energy in an ejector, thereby reducing motive power consumed by the compressor. Further, refrigerant is circulated into an evaporator of the ejector cycle by using a pumping function of the ejector. However, when energy converting efficiency of the ejector, that is, ejector efficiency is reduced, 20 the pressure of refrigerant to be sucked to the compressor cannot be sufficiently increased by the ejector. In this case, the motive power consumed by the compressor cannot be satisfactorily 25

reduced. On the other hand, a throttle degree (passage opening degree) of the nozzle is fixed in the ejector. Therefore, when an amount of refrigerant flowing into the nozzle changes, a nozzle efficiency and the ejector efficiency are changed in accordance
5 with the change of the refrigerant flowing amount. Here, the nozzle efficiency is an energy converting efficiency of the nozzle when the pressure energy is converted to the speed energy in the nozzle.

Further, according to experiments by the inventor of the
10 present invention, if only an opening degree of a throat portion of the nozzle is simply changed, vertical shock wave is generated between a throat portion and an outlet of the nozzle, and the pressure of refrigerant is rapidly changed therebetween. Accordingly, at the outlet of the nozzle, a fluid (refrigerant)
15 is in a subsonic state, and is super-expended. As a result, the refrigerant is not decompressed in iso-entropy in the nozzle, and the nozzle efficiency may be greatly reduced.

SUMMARY OF THE INVENTION

20 In view of the foregoing problems, it is an object of the present invention to provide an ejector which can sufficiently increase nozzle efficiency regardless of a flow amount of refrigerant.

It is another object of the present invention to provide
25 an ejector cycle using the ejector.

According to the present invention, an ejector includes a nozzle for defining therein a passage through which a drive fluid

flows, and a pressure-increasing portion in which a fluid is sucked by entrainment of a jet flow of the drive fluid injected from the nozzle and is mixed with the drive fluid injected from the nozzle. In the ejector, the nozzle includes a throat portion having a cross-sectional area that is smallest in the passage of the nozzle, and an adjustment unit is disposed to adjust an opening degree of the throat portion and an opening degree of an outlet of the nozzle. Because both the opening degrees of the throat portion and the outlet of the nozzle are controlled by the adjustment unit, it can effectively restrict vertical shock wave from being generated even when the flow amount of the drive fluid flowing into the nozzle is changed. Therefore, it can prevent a super-expansion state, where the flow speed of the drive fluid at the outlet of the nozzle becomes subsonic, from being caused. Accordingly, nozzle efficiency can be sufficiently increased regardless of the flow amount of the drive fluid flowing into the nozzle.

Preferably, the adjustment unit includes a needle valve that extends at least from the throat portion to the outlet of the nozzle. Therefore, both the opening degrees of the throat portion and the outlet of the nozzle can be readily controlled simultaneously. Generally, the needle valve is disposed to be moved in an axial direction of the nozzle.

The ejector of the present invention can be suitably used for an ejector cycle including a compressor for compressing and discharging a refrigerant, a first heat exchanger disposed for cooling the refrigerant discharged from the compressor, a

gas-liquid separator for separating refrigerant from the ejector into gas refrigerant and liquid refrigerant, and a second heat exchanger disposed for evaporating liquid refrigerant from the gas-liquid separator. In this case, the refrigerant from the
5 first heat exchanger is decompressed in the nozzle, and the refrigerant evaporated in the evaporator is sucked into a pressure-increasing portion of the ejector. The refrigerant from the nozzle and the refrigerant from the evaporator are mixed in the pressure-increasing portion while the pressure of
10 refrigerant is increased in the pressure-increasing portion. Accordingly, the ejector cycle can be operated while the nozzle efficiency can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Additional objects and advantages of the present invention will be more readily apparent from the following detailed description of a preferred embodiment when taken together with the accompanying drawings, in which:

FIG. 1 is a schematic diagram showing an ejector cycle
20 according to a preferred embodiment of the present invention;

FIG. 2A is a schematic sectional view showing an ejector according to the embodiment, and FIG. 2B is a schematic enlarged view showing a part of a nozzle of the ejector in FIG. 2A;

FIG. 3 is a Mollier diagram (p-h diagram) showing a
25 relationship between a refrigerant pressure and an enthalpy in the ejector cycle;

FIG. 4 is a view for explaining a problem in a comparison

example; and

FIG. 5 is a graph showing nozzle efficiency in the present invention and in the comparison example.

5 DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENT

A preferred embodiment of the present invention will be described hereinafter with reference to the appended drawings.

In the embodiment, an ejector of an ejector cycle is typically used for an air conditioner. In the ejector cycle shown

10 in FIG. 1, fluorocarbon (fleon, 134a) or carbon dioxide or the like can be used as a refrigerant. In the ejector cycle, a

compressor 10 sucks and compresses refrigerant by power obtained from a vehicle engine. A discharge capacity (displacement) of

the compressor 10 is controlled so that a temperature or a pressure in the evaporator 30 becomes in a predetermined range.

15 A radiator 20 is disposed to cool the refrigerant discharged from the compressor 10. Specifically, the radiator 20 is a high-pressure heat exchanger that performs heat-exchange between the refrigerant flowing from the compressor 10 and outside air.

20 An evaporator 30 is disposed to evaporate liquid refrigerant.

Specifically, the evaporator 30 is a low-pressure heat exchanger that evaporates the liquid refrigerant by absorbing heat from air passing therethrough. Therefore, air passing through the evaporator 30 is cooled, and the cooled air can be blown into

25 a compartment to cool the compartment.

An ejector 40 sucks refrigerant evaporated in the evaporator 30 while decompressing and expanding refrigerant flowing from

the radiator 20, and increases pressure of refrigerant to be sucked into the compressor 10 by converting expansion energy to pressure energy.

A gas-liquid separator 50 separates the refrigerant from the ejector 40 into gas refrigerant and liquid refrigerant, and stores the separated refrigerant therein. The gas-liquid separator 50 includes a gas-refrigerant outlet connected to a suction port of the compressor 10, and a liquid-refrigerant outlet connected to an inlet side of the evaporator 30. A throttle 60 is disposed in a refrigerant passage between the liquid-refrigerant outlet of the gas-liquid separator 50 and the inlet side of the evaporator 30, so that liquid refrigerant supplied from the gas-liquid separator 50 to the evaporator 30 is decompressed.

In the ejector cycle, reference numbers C1-C9 shown in FIG. 3 indicate refrigerant states at positions indicated by reference numbers C1-C9 shown in FIG. 1, respectively, when carbon dioxide is used as the refrigerant.

Next, the structure of the ejector 40 will be now described in detail with reference to FIGS. 1, 2A and 2B. As shown in FIG. 2, the ejector 40 includes a nozzle 41, a mixing portion 42 and a diffuser 43. The nozzle 41 decompresses and expands high-pressure refrigerant from the radiator 20 in iso-entropy by converting pressure energy of the high-pressure refrigerant to speed energy. Gas refrigerant from the evaporator 30 is sucked into the mixing portion 42 by a high speed stream of refrigerant injected from the nozzle 41, and the sucked gas refrigerant and

the injected refrigerant are mixed in the mixing portion 42. The diffuser 43 increases refrigerant pressure by converting the speed energy of refrigerant to the pressure energy of the refrigerant while mixing the gas refrigerant sucked from the 5 evaporator 30 and the refrigerant injected from the nozzle 41.

In the mixing portion 42, the refrigerant jetted from the nozzle 41 and the refrigerant sucked from the evaporator 30 are mixed so that the sum of their momentum of two-kind refrigerant flows is conserved. Therefore, static pressure of refrigerant 10 is increased also in the mixing portion 42. Because a sectional area of a refrigerant passage in the diffuser 43 is gradually increased, dynamic pressure of refrigerant is converted to static pressure of refrigerant in the diffuser 43. Thus, refrigerant pressure is increased in both of the mixing portion 42 and the 15 diffuser 43. Accordingly, in the embodiment, a pressure-increasing portion is constructed with the mixing portion 42 and the diffuser 43. Theoretically, in the ejector 40, refrigerant pressure is increased in the mixing portion 42 so that the total momentum of two-kind refrigerant flows is conserved in the mixing 20 portion 42, and the refrigerant pressure is further increased in the diffuser 43 so that total energy of refrigerant is conserved in the diffuser 43.

The nozzle 41 is a Laval nozzle having a throat portion 41a and an expansion portion 41b that is downstream from the throat 25 portion 41a. Here, a cross-sectional area of the throat portion 41a is smallest in a refrigerant passage of the nozzle 41. As shown in FIG. 2A, an inner radial dimension of the expansion

portion 41b is gradually increased from the throat portion 41a toward a downstream end (outlet) of the nozzle 41. A needle valve 44 is displaced by an actuator 45 in an axial direction of the nozzle 41, so that a throttle degree of the refrigerant passage 5 of the nozzle 41 is adjusted. That is, the throttle degree of the refrigerant passage in the nozzle 41 is adjusted by the displacement of the needle valve 44. In this embodiment, an opening degree of the throat portion 41a and an opening degree 10 of the outlet of the expansion portion 41b of the nozzle 41 are simultaneously or independently controlled by an adjustment unit such as the needle valve 44, so that the throttle degree of the refrigerant passage of the nozzle 41 is adjusted. The single needle valve 44 is disposed to extend at least from the throat portion 41a to the outlet of the expansion portion 41b, so that 15 both the opening degree of the throat portion 41a and the opening degree of the outlet of the expansion portion 41b of the nozzle 41 are adjusted. By suitably adjusting both the opening degree of the throat portion 41a and the opening degree of the outlet of the nozzle 41, it can prevent a vertical shock wave from being 20 generated between the throat portion 41a and the outlet of the nozzle 41. Therefore, nozzle efficiency can be improved regardless of a change of the flow amount of the refrigerant flowing into the nozzle 41.

In this embodiment, an electric actuator such as a linear 25 solenoid motor and a stepping motor including a screw mechanism is used as the actuator 45. Further, the pressure of the high-pressure refrigerant is detected by a pressure sensor (not

shown). Then, the open degree of the throat portion 41a and the opening degree of the outlet of the nozzle 41 are adjusted by the needle valve 41, so that the pressure detected by the pressure sensor becomes a target pressure that is determined based on a detected temperature of a temperature sensor. The temperature sensor is disposed at the high pressure side to detect the temperature of the high-pressure side refrigerant in the ejector cycle. The target pressure is set so that the coefficient of the ejector cycle becomes maximum, relative to the refrigerant temperature at the high-pressure side in the ejector cycle. As shown in FIG. 3, when the carbon dioxide is used as the refrigerant, the pressure of the high-pressure side refrigerant becomes higher than the critical pressure of the refrigerant. In this case, the opening area of the refrigerant passage of the nozzle 41 is controlled so that the pressure of the refrigerant flowing into the nozzle becomes equal to or higher than the critical pressure. On the other hand, when the pressure of the refrigerant flowing into the nozzle 41 is lower than the critical pressure of the refrigerant, the opening area of the refrigerant passage of the nozzle 41 is controlled so that refrigerant flowing into the nozzle 41 has a predetermined super-cooling degree.

In the ejector cycle, refrigerant is compressed in the compressor 10, and is discharged to the radiator 20. The refrigerant discharged from the compressor 10 is cooled in the radiator 20, and is decompressed in the nozzle 41 of the ejector 40 generally in iso-entropy. The flow speed of the refrigerant is increased in the nozzle 41 of the ejector 40 to be equal to

or more than the sound speed at the outlet of the nozzle 41, and flows into the mixing portion 42 of the ejector 40. Further, gas refrigerant evaporated in the evaporator 30 is sucked into the mixing portion 42 of the ejector 40 by the pumping function due to the entrainment function of the high-speed refrigerant flowing from the nozzle 41 into the mixing portion 42. The refrigerant sucked from the evaporator 30 and the refrigerant injected from the nozzle 41 are mixed in the mixing portion 42, and flows into the gas-liquid separator 50 after the dynamic pressure of the refrigerant is converted to the static pressure of the refrigerant in the diffuser 43. Therefore, low-pressure side refrigerant circulates from the gas-liquid separator 50 to the gas-liquid separator 50 through the throttle 60, the evaporator 30 and the pressure-increasing portion of the ejector 40 in this order.

In an ideal nozzle 41, the refrigerant flowing into the nozzle 41 is throttled as toward the throat portion 41a from the inlet of the nozzle 41, and the flow speed of the refrigerant increases toward the throat portion 41a from the inlet of the nozzle 41. Then, at the throat portion 41a, the refrigerant becomes in the critical state, and the flow speed becomes Mach 1. Refrigerant after passing through the throat portion 41a is boiled and expanded in the expansion portion 41b, and the flow speed of the refrigerant becomes more than Mach 1 in the expansion portion 41b of the nozzle 41.

However, in an actual refrigerant cycle, the refrigerant flow amount flowing into the nozzle 41 is changed in accordance

with an air-conditioning load. Therefore, generally, the passage sectional areas of the throat portion 41a and the outlet of the expansion portion 41b of the nozzle 41 are set and formed based on the maximum flow amount in the maximum air-conditioning 5 load, and the opening degree of the throat portion 41a is reduced when the refrigerant flow amount is reduced due to a reduced air-conditioning load. In a comparison example shown in FIG. 4 where only the opening degree of the throat portion 41 is controlled when the flow amount of the refrigerant is changed, 10 because the opening degree of the outlet of the nozzle 41 is fixed, the refrigerant pressure in the expansion portion 41b around the outlet of the expansion portion 41b becomes lower than the refrigerant pressure outside the nozzle 41 around the outlet of the expansion portion 41b. Therefore, the vertical shock wave 15 is readily generated, and the flow speed of the refrigerant at the outlet of the nozzle 41 becomes in the subsonic state, and the refrigerant is super-expanded at the outlet of the nozzle 41. Accordingly, in the comparison example, the refrigerant is not decompressed in iso-entropy in the nozzle 41, and the nozzle 20 efficiency is greatly reduced as the flow amount of the refrigerant in the nozzle 41 is reduced, as shown in FIG. 5.

According to the present invention, the needle valve 44 is disposed in the refrigerant passage in the nozzle 41 to extend at least to the outlet (downstream end) of the nozzle 41. 25 Therefore, by the movement of the needle valve 44 in the axial direction of the nozzle 41, both the opening degree of the throat portion 41a and the opening degree of the outlet of the nozzle

41 can be controlled. Accordingly, even when the flow amount
of the refrigerant flowing into the nozzle 41 is changed in the
general using area shown in FIG. 5, the nozzle efficiency can
be maintained approximately in the maximum value by controlling
5 both the opening degrees of the throat portion 41 and the outlet
of the nozzle 41, as shown in FIG. 5. In FIG. 5, P₁ shows a state
where a cool-down operation is performed in the air conditioner
in a high vehicle speed. That is, p₁ shows a large cooling load
state.

10 In the present invention, the opening degree of the throat
portion 41a and the opening degree of the outlet of the nozzle
41 are adjusted by the needle valve 44 and the actuator 45, so
that it can prevent the vertical shock wave from being generated
in the nozzle 41. Therefore, it can prevent the refrigerant from
15 being in a super-expansion state due to the subsonic flow at the
outlet of the nozzle.

20 Although the present invention has been fully described in
connection with the preferred embodiment thereof with reference
to the accompanying drawings, it is to be noted that various changes
and modifications will become apparent to those skilled in the
art.

25 In the above-described embodiment, the present invention is
typically applied to the vehicle air conditioner. However, the
present invention can be applied to another ejector cycle such
as a refrigerator, a freezer and a water heater. The actuator
45 may be a mechanical actuator using the pressure of inert gas
or may be a non-electromagnetic electric actuator using

piezoelectric elements. For example, the electric actuator is a stepping motor or a linear solenoid motor.

In the above-described embodiment, by using the single needle valve 44 operated by the actuator 45, both the opening degree of the throat portion 41a and the opening degree of the outlet of the nozzle 41 are simultaneously controlled. However, in the present invention, a valve for controlling the opening degree of the throat portion 41a and a valve for controlling the opening degree of the outlet of the nozzle 41 can be independently provided. Even in this case, by suitably controlling both the opening degrees of the throat portion 41a and the outlet of the nozzle 41, the decompression degree of the nozzle 41 is suitably adjusted, and the nozzle efficiency can be effectively improved.

Such changes and modifications are to be understood as being within the scope of the present invention as defined by the appended claims.